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Wang et al.

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(54) **ROLLER HEMMING**

(71) Applicants: **GM Global Technology Operations LLC**, Detroit, MI (US); **Shanghai Jiao Tong University**, Shanghai (CN)

(72) Inventors: **Jeff Wang**, Jiangsu (CN); **Xianghuai Dong**, Shanghai (CN); **Yao Shen**, Shanghai (CN); **Jun Chen**, Shanghai (CN)

(73) Assignees: **GM Global Technologies Operations LLC**, Detroit, MI (US); **Shanghai Jiao Tong University**, Shanghai (CN)

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B21D 37/16 (2006.01)

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CPC ***B21D 39/023*** (2013.01); ***B21D 19/043*** (2013.01); ***B21D 37/16*** (2013.01)

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USPC 72/200, 202, 219, 220, 342.94, 312, 72/313, 314, 315, 342.96, 252.5; 219/50, 219/162, 81, 82, 83, 84; 29/419.2, 513; 901/17, 18
See application file for complete search history.

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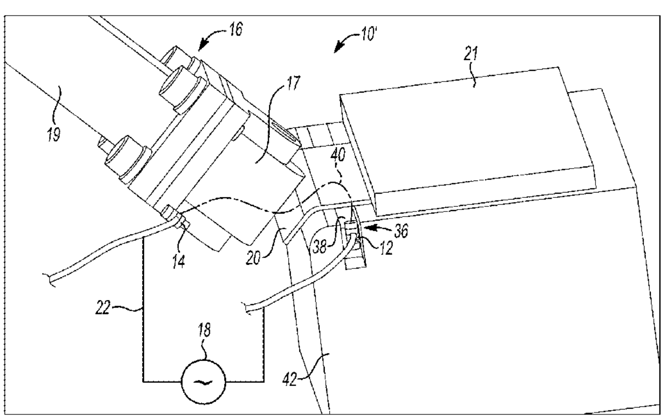
Primary Examiner — Shelley Self
Assistant Examiner — Gregory Swiatocha
(74) *Attorney, Agent, or Firm* — Dierker & Kavanaugh, P.C.

(57) **ABSTRACT**

Methods and apparatuses for roller hemming are disclosed herein. An example of a sheet metal roller hemming apparatus includes a first electrode to electrically connect to an electrical power supply and a sheet metal workpiece. The apparatus further includes a second electrode to electrically connect to the electrical power supply and the sheet metal workpiece to cause pulsed electric current to flow through a portion of the workpiece to locally increase formability in the portion of the workpiece. The apparatus still further includes a roller assembly to contact the workpiece to cause the workpiece to bend in the portion of the workpiece when the pulsed electric current is flowing through the portion of the workpiece, and to form a hem.

2 Claims, 11 Drawing Sheets



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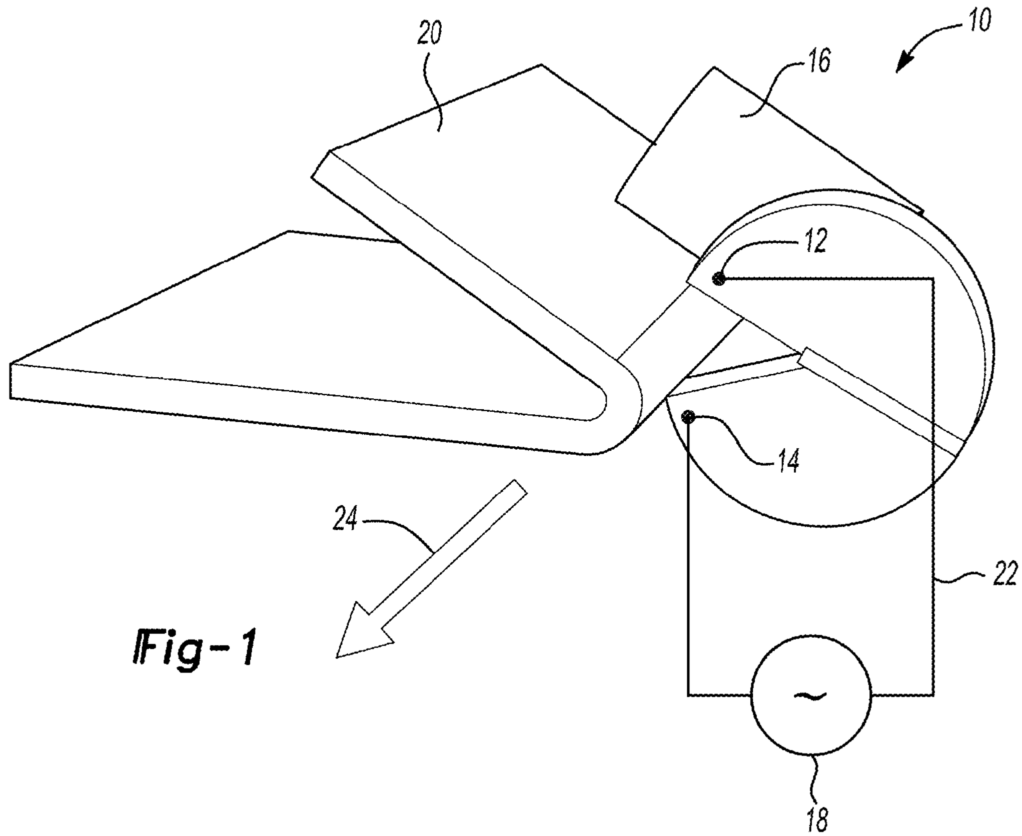


Fig-1

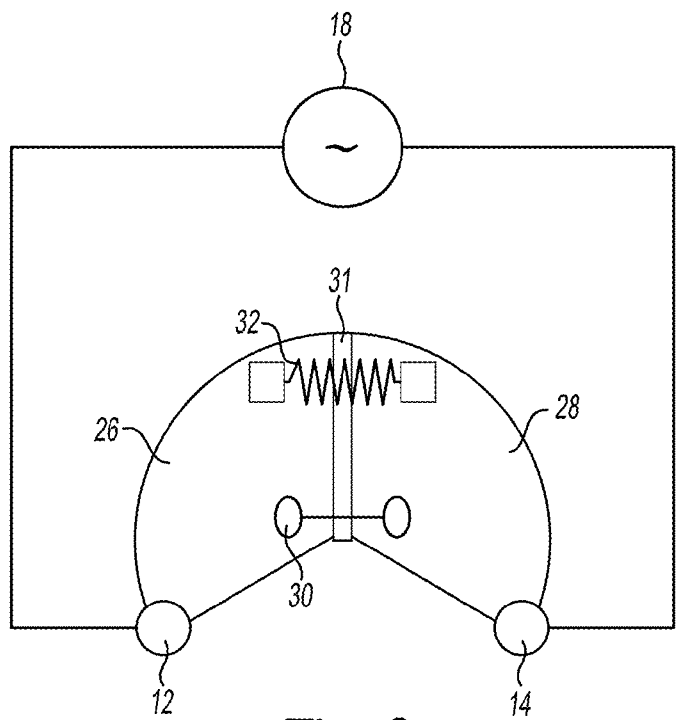


Fig-2

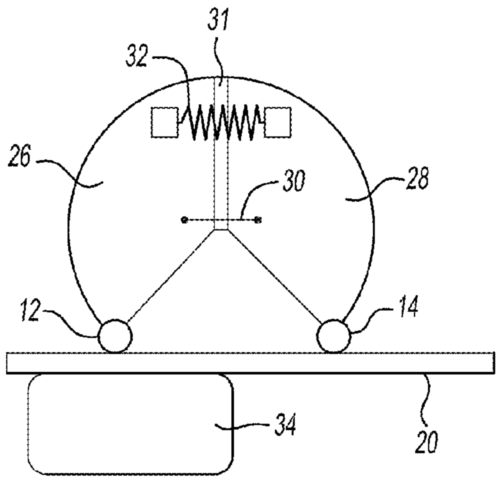


Fig-3A

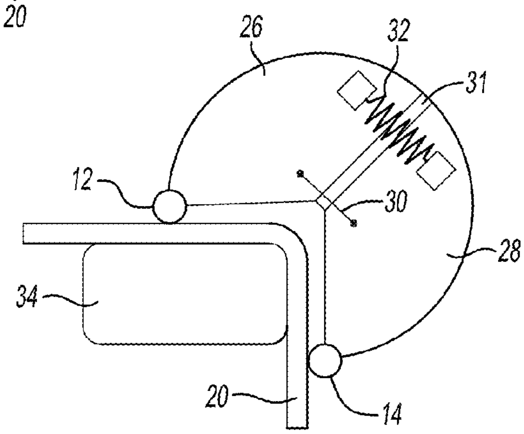


Fig-3B

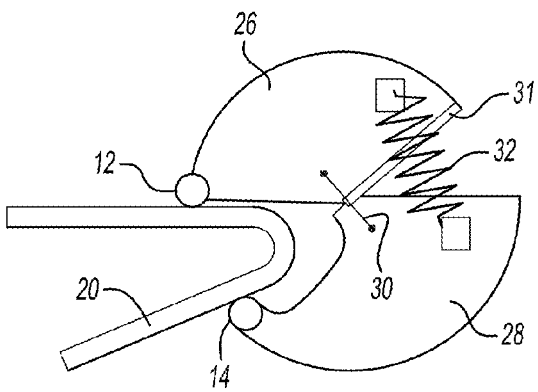


Fig-3C

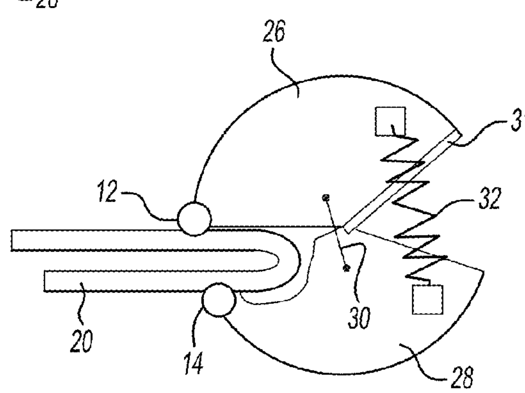


Fig-3D

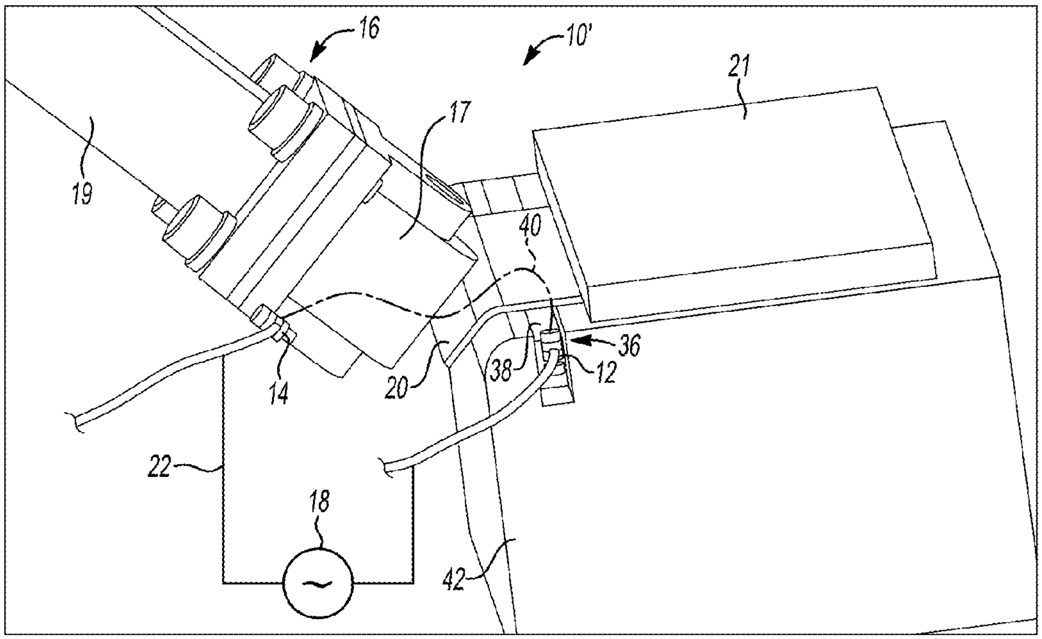


Fig-4

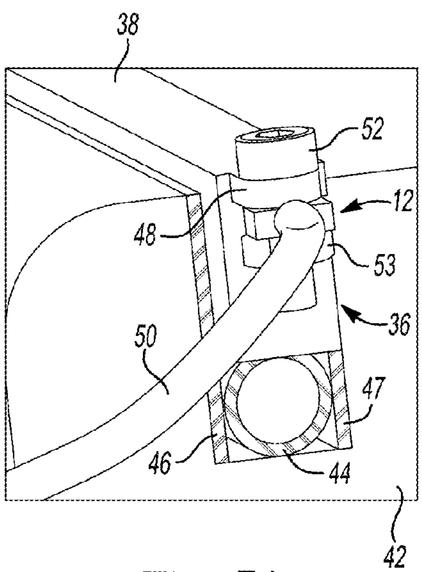


Fig-5A

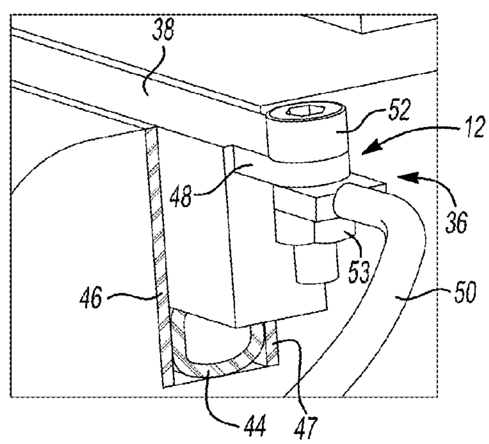
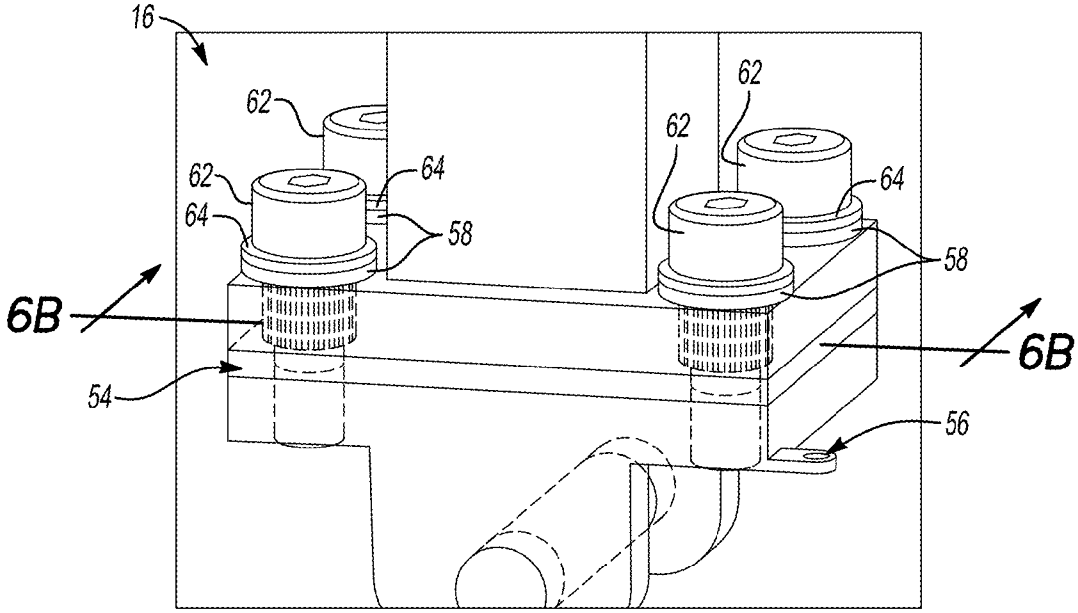


Fig-5B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6B
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Fig-6A

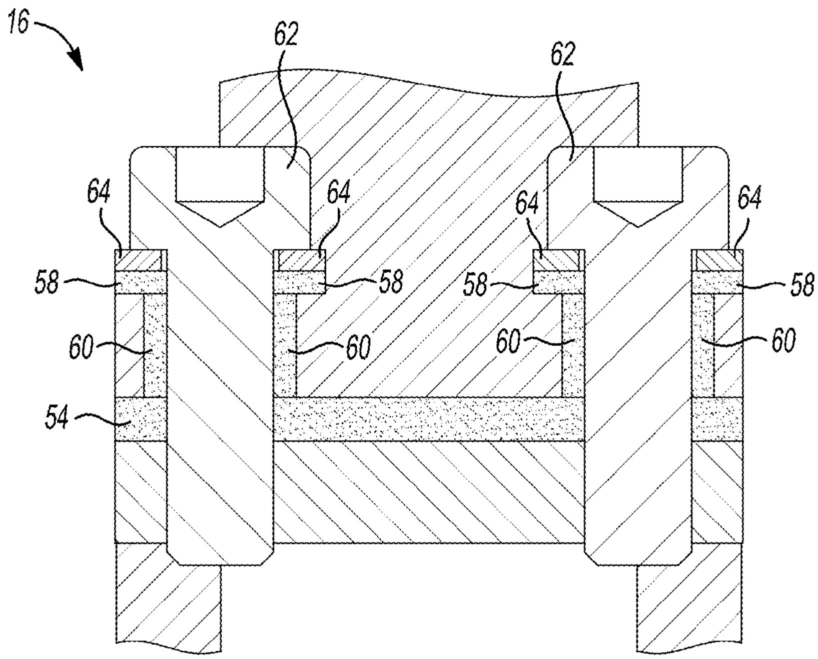
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Fig-6B

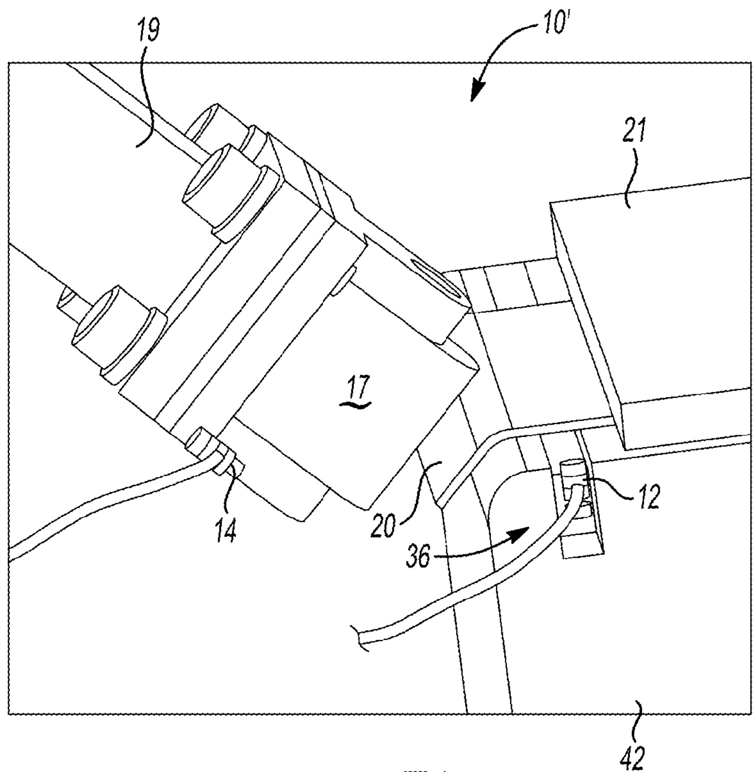

Fig-7A

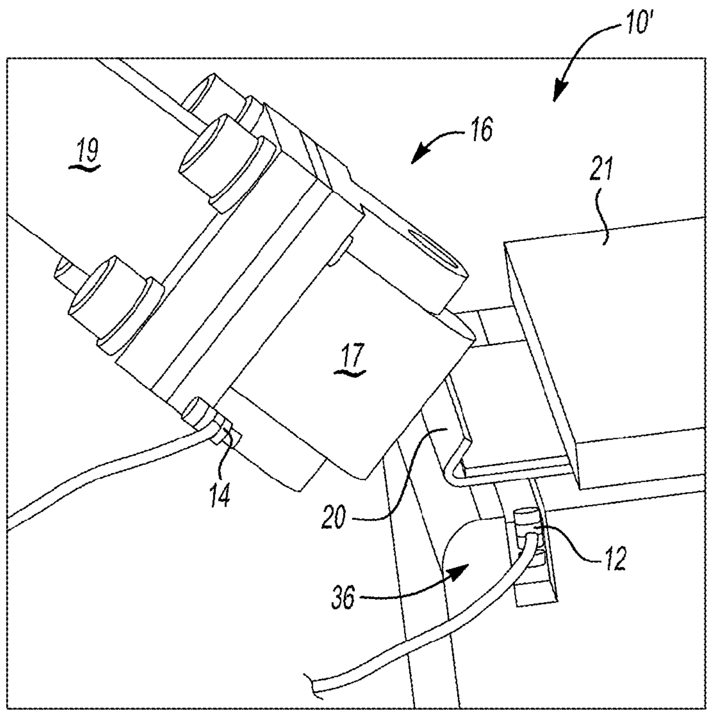

Fig-7B

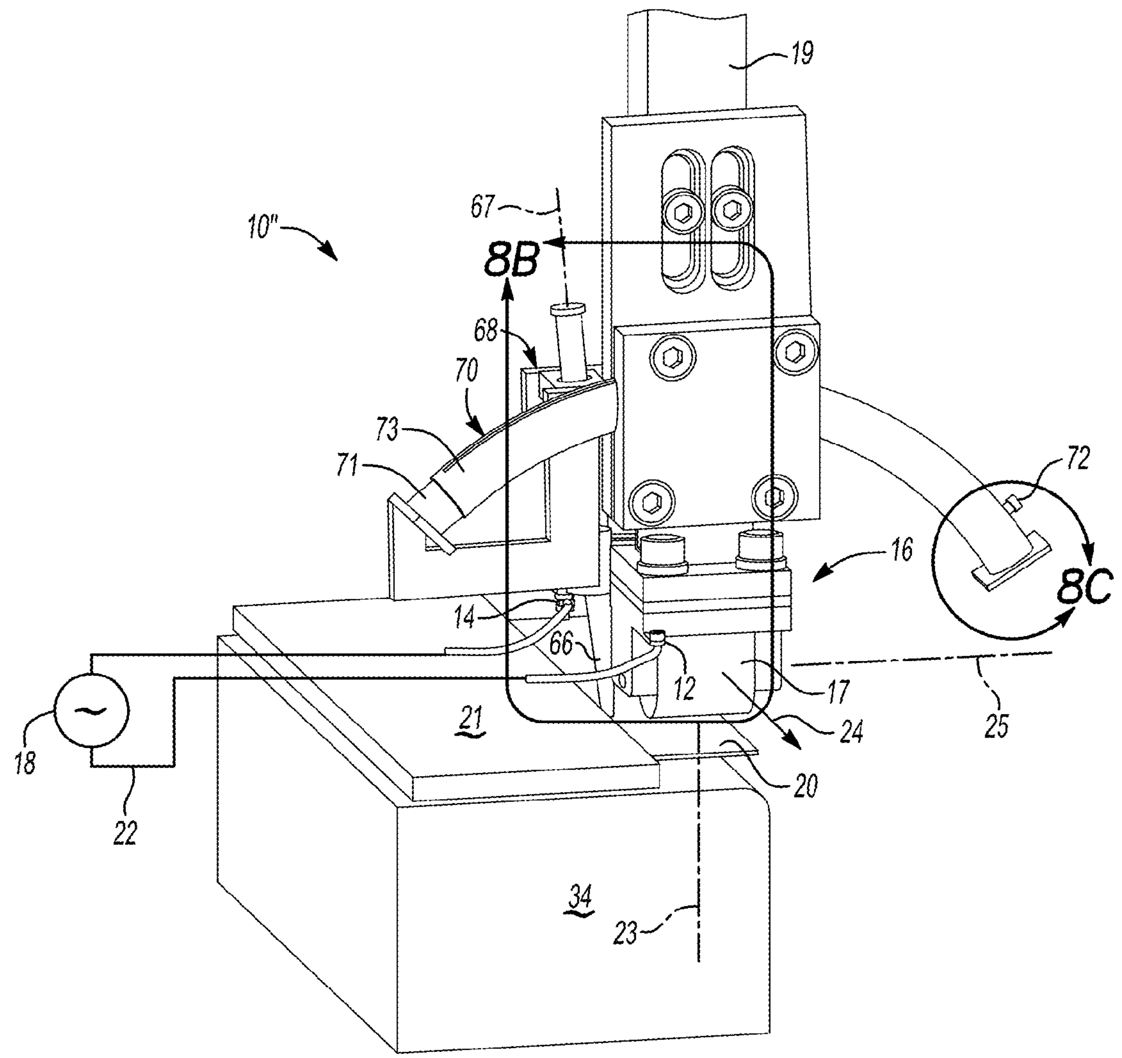

Fig-8A

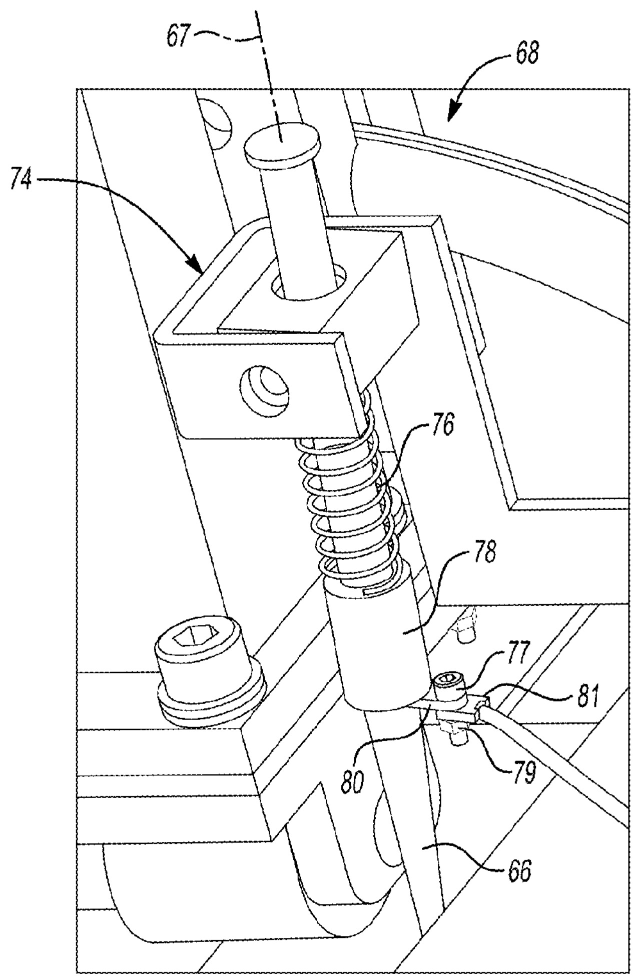

Fig-8B

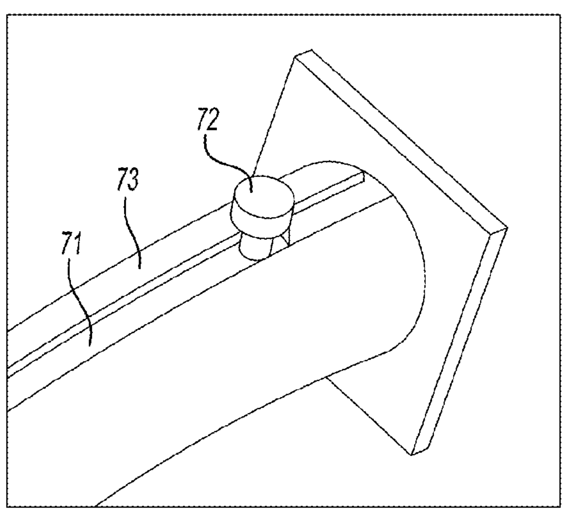

Fig-8C

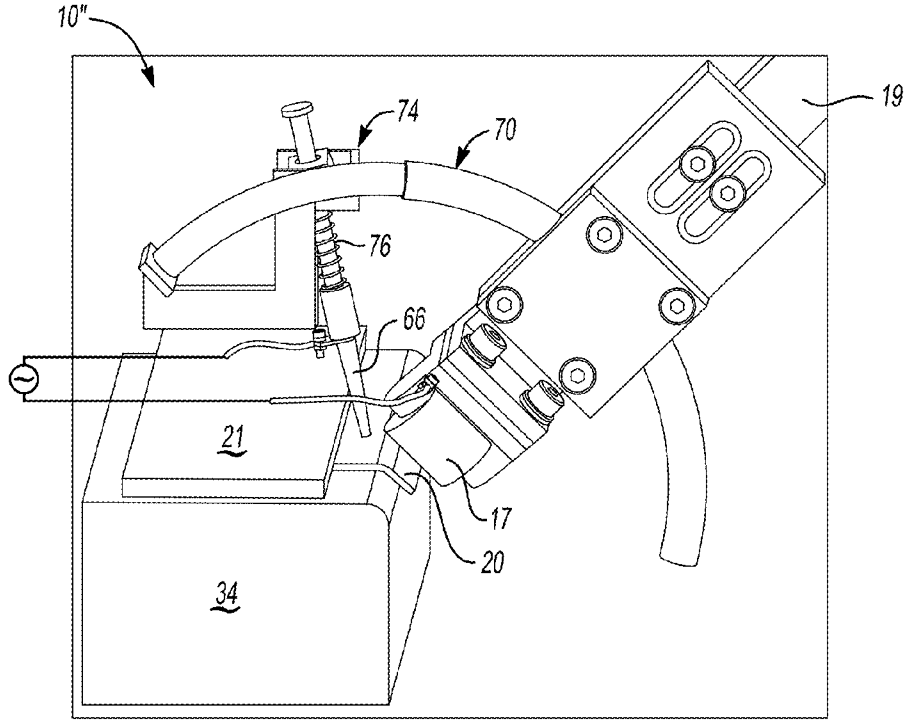

Fig-8D

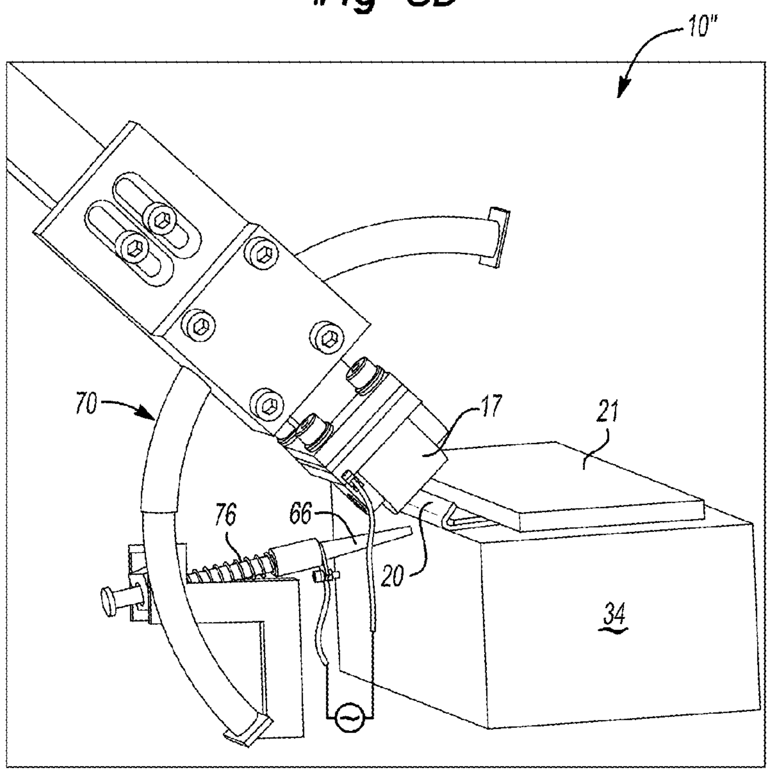

Fig-8E

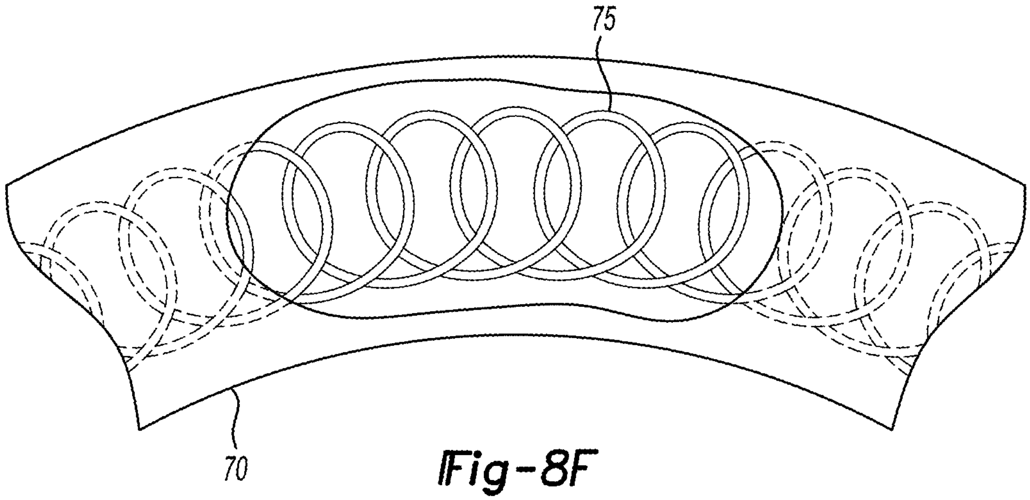

Fig-8F

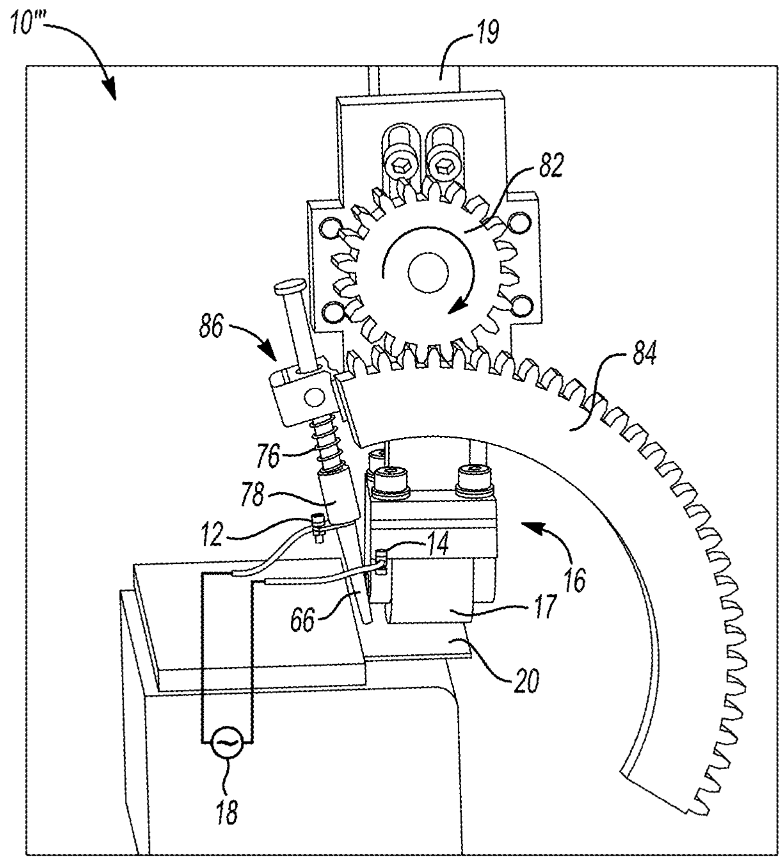

Fig-9A

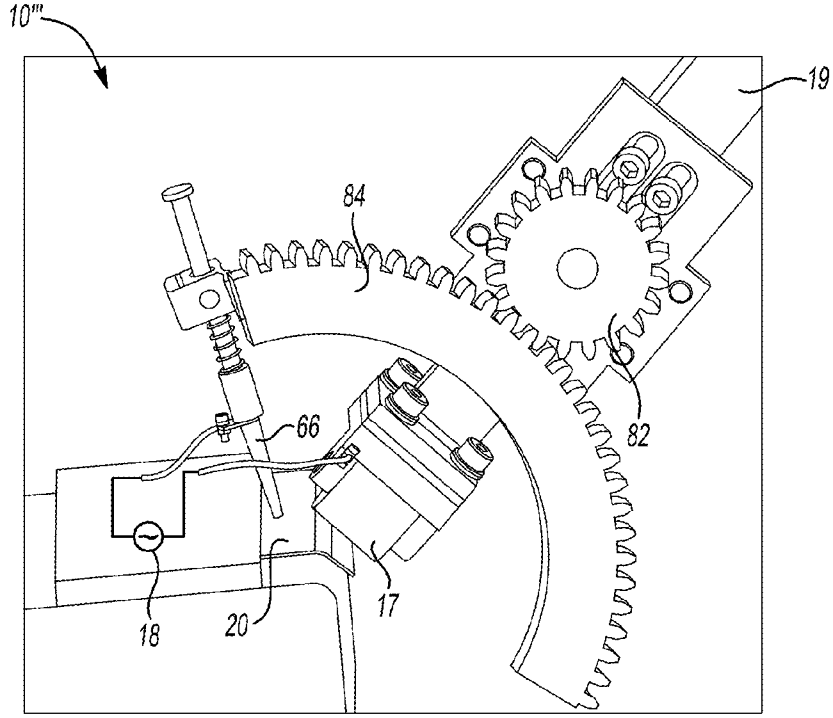

Fig-9B

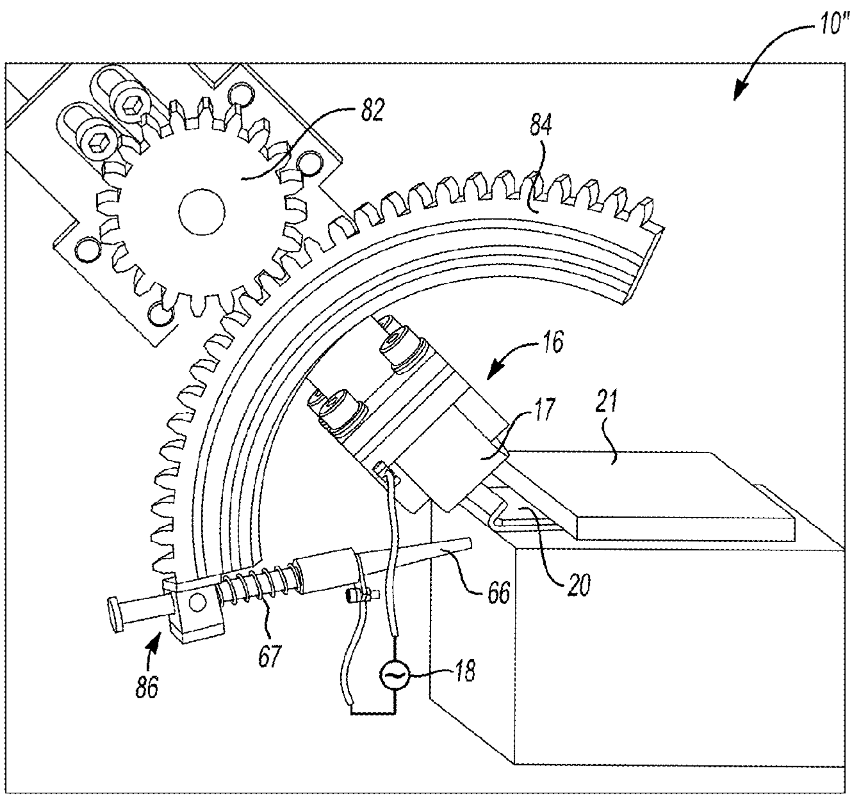

Fig-9C

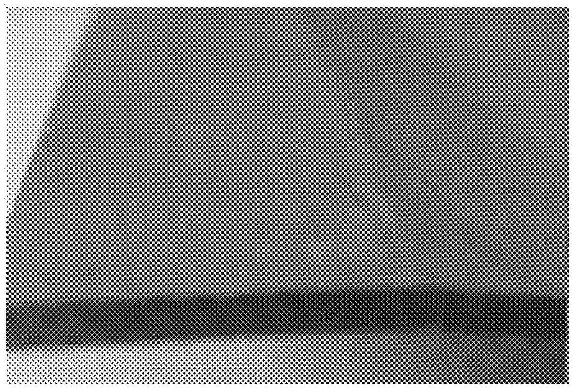

Fig-10A

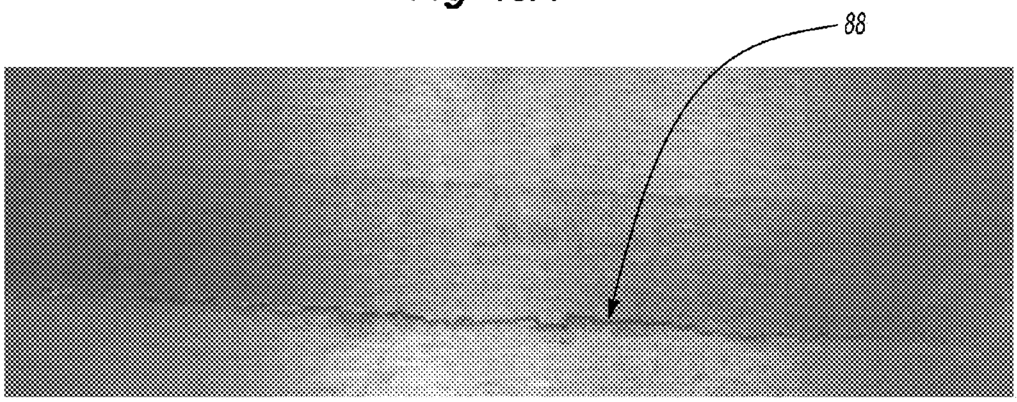

Fig-10B

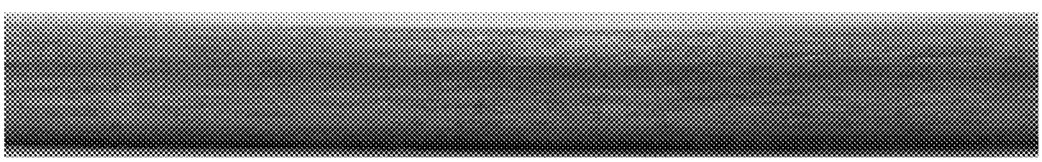

Fig-11A

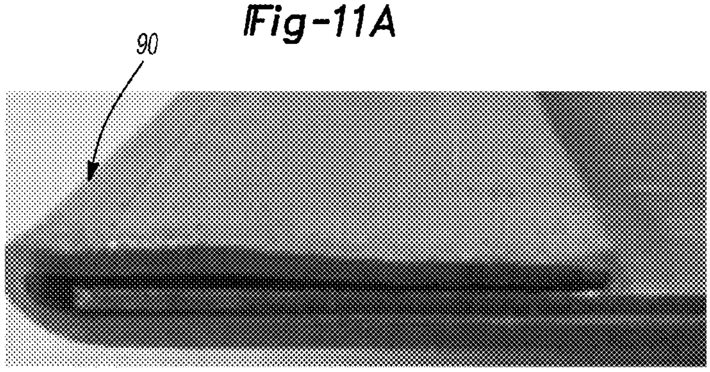

Fig-11B

ROLLER HEMMING

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is based on and claims the benefit of priority from Chinese Patent Application No. 201210501564.4, filed on Nov. 30, 2012, the contents of which are incorporated by reference herein.

TECHNICAL FIELD

The present disclosure relates generally to roller hemming.

BACKGROUND

Roller hemming is a forming process which includes deforming a metal sheet into a hemmed configuration. For example, automotive components including doors, hoods, and tailgates may be hemmed. An example of a roller hemming process may include a flanging step and a hemming step. The flanging step creates a preliminary bend contour in the metal sheet, and the hemming step closes the hem so the edge is rolled flush to itself.

SUMMARY

Methods and apparatuses for roller hemming are disclosed herein. An example of a sheet metal roller hemming apparatus includes a first electrode to electrically connect to an electrical power supply and a sheet metal workpiece. The apparatus further includes a second electrode to electrically connect to the electrical power supply and the sheet metal workpiece to cause pulsed electric current to flow through a portion of the workpiece to locally increase formability in the portion of the workpiece. The apparatus still further includes a roller assembly to contact the workpiece to cause the workpiece to bend in the portion of the workpiece when the pulsed electric current is flowing through the portion of the workpiece, and to form a hem.

BRIEF DESCRIPTION OF THE DRAWINGS

Features and advantages of examples of the present disclosure will become apparent by reference to the following detailed description and drawings, in which like reference numerals correspond to similar, though perhaps not identical, components. For the sake of brevity, reference numerals or features having a previously described function may or may not be described in connection with other drawings in which they appear.

FIG. **1** is a schematic, perspective view of an example of a sheet metal roller hemming apparatus according to the present disclosure;

FIG. **2** is a schematic diagram depicting components of an example of a sheet metal roller hemming apparatus according to the present disclosure;

FIGS. **3**A-**3**D are schematic diagrams depicting a method of using the apparatuses of FIGS. **1** and **2** according to the present disclosure;

FIG. **4** is a semi-schematic, perspective view of another example of a sheet metal roller hemming apparatus according to the present disclosure;

FIGS. **5**A-**5**B are semi-schematic, perspective views of an example of a busbar according to the present disclosure;

FIG. **6**A is a semi-schematic, perspective view of an example of an electrical isolation mechanism of a roller assembly according to the present disclosure;

FIG. **6**B is a semi-schematic, cross-sectional view of the electrical isolation mechanism taken along the **6**B-**6**B line of FIG. **6**A;

FIGS. **7**A and **7**B are semi-schematic, perspective views of the other example of the sheet metal roller hemming apparatus according to the present disclosure during a flanging step and a hemming step, respectively;

FIG. **8**A is a semi-schematic, perspective view of still another example of a sheet metal roller hemming apparatus according to the present disclosure;

FIG. **8**B is a semi-schematic, enlarged perspective view of a portion of the example of the sheet metal roller hemming apparatus of FIG. **8**A;

FIG. **8**C is a semi-schematic, enlarged perspective view of another portion of the example of the sheet metal roller hemming apparatus of FIG. **8**A;

FIGS. **8**D and **8**E are semi-schematic, perspective views of the example of the sheet metal roller hemming apparatus of FIG. **8**A during a flanging step and a hemming step, respectively;

FIG. **8**F is a semi-schematic, enlarged cutaway-perspective view of an arcuate telescoping connection of the example of the sheet metal roller hemming apparatus of FIG. **8**A;

FIG. **9**A is a semi-schematic, perspective view of yet another example sheet metal roller hemming apparatus;

FIGS. **9**B and **9**C are semi-schematic, perspective views of the example sheet metal roller hemming apparatus of FIG. **9**A during a flanging step and a hemming step, respectively;

FIG. **10**A is a black and white representation of an originally colored optical microscopy photograph showing a top, perspective view of a portion of a comparative test bend formed via a traditional bending process;

FIG. **10**B is a black and white representation of an originally colored optical microscopy photograph showing a bottom surface of the comparative test bend shown in FIG. **10**A;

FIG. **11**A is a black and white representation of an originally colored optical microscopy photograph showing a front view of a curved hemmed surface of an example test hemmed workpiece formed via a method according to the present disclosure; and

FIG. **11**B is a black and white representation of an originally colored optical microscopy photograph showing a side perspective view of the example test hemmed workpiece shown in FIG. **11**A.

DETAILED DESCRIPTION

Roller hemming of a metal sheet is a process used, for example, in the automotive industry to form body panels and other components. Hemming certain materials at room temperature may be difficult due to poor formability of those materials. For example, room temperature hemming of magnesium and other like materials may be difficult, at least in part because these materials do not readily deform. Some methods of roller hemming have included heat assistance by laser or induction coils. Other methods of roller hemming have included electromagnetic force, which may provide increased ductility due to high speed deformation. Further, a Jewel effect appearance along the hemline may be difficult to achieve, for example, when roller hemming particular materials, such as aluminum and magnesium sheets. It is to be understood that a Jewel effect refers generally to a high quality appearance. With reference to a hemline, the Jewel effect includes the perceived sharpness of a hem edge and also the perceived gap between a panel hem edge and another panel.

Examples of the present disclosure include electric pulsing in roller hemming sheet metal, i.e., a workpiece. Examples of the present disclosure may increase formability and hemmability of the workpiece, thereby reducing deformation resistance of the sheet metal workpiece (i.e., locally reducing yield strength and increasing ductility of the workpiece). Examples of the present disclosure may also reduce process cycle time and improve finished-part surface quality of hemmed metal sheets, including aluminum and magnesium sheets. It is to be understood that the electric pulsing disclosed herein may increase formability in the workpiece due to both joule heating and an electroplasticity effect. This is unlike laser-assisted hemming processes that introduce heat alone to the workpiece. In contrast, the electroplasticity effect resulting from the electric pulsing may increase the formability of the workpiece by depinning dislocations from obstacles with electron wind assistance and/or magnetic field assistance. Electric pulsing according to examples of the present disclosure may anneal the workpiece, allowing a reduced force to be used to form a flange and hem on the workpiece.

Referring now to FIG. **1**, an example of a sheet metal roller hemming apparatus is depicted generally at **10**. The hemming apparatus **10** includes a first electrode **12**, a second electrode **14**, and a roller assembly **16**. The first electrode **12** may be electrically connected to an electrical power supply **18**, and may be placed into electrical connection with the sheet metal workpiece **20**. The second electrode **14** also may be electrically connected to the electrical power supply **18**, and may be placed into electrical connection with the sheet metal workpiece **20**. An electrical circuit, designated generally by **22**, may include the first electrode **12**, the second electrode **14**, the sheet metal workpiece **20**, and the electrical power supply **18**. The electrical circuit **22** may cause pulsed electric current to flow through a portion of the workpiece **20** to locally increase formability of the portion of the workpiece **20**. As will be discussed further below in reference to at least FIG. **4**, it is also possible to use the roller assembly **16** as the first electrode **12** or the second electrode **14**. Still further, in any of the examples disclosed herein, another (second) pair of electrodes (not shown) may be configured to follow the roller assembly **16** along the workpiece **20** to anneal the deformed area of the workpiece **20**.

Referring briefly to FIG. **2**, some components of the example of the hemming apparatus **10** of FIG. **1** are shown. The hemming apparatus **10** may have a hinged pivotal connection for accommodating contact of electrodes **12**, **14** with the workpiece **20** (not shown in FIG. **2**). FIG. **2** shows a first hinged element **26** and a second hinged element **28** pivotally connected by a hinge **30**.

In an example, the first hinged element **26** and the second hinged element **28** may operate as the first electrode **12** and second electrode **14**, respectively. In this example, each of the first hinged element **26** and the second hinged element **28** may be electrically conductive. The first and second hinged elements **26**, **28** may be separated from one another by an insulator **31** made of, for example, phenolic plastic or another suitable insulating material. When the first and second hinged elements **26**, **28** function as the electrodes **12**, **14**, the insulator **31** electrically isolates the two elements **26**, **28**.

In another example, the first hinged element **26** and the second hinged element **28** may be formed of electrically insulating materials (e.g., phenolic plastic), and these elements **26**, **28** may hold electrically conductive components that operate, respectively, as first electrode **12** and second electrode **14**. This example is shown in FIG. **2**. The electrodes **12**, **14** may be bonded to the first and second hinged elements **26**, **28**.

In any of the examples disclosed herein, the size of electrodes **12**, **14** may range from about 5 mm to about 50 mm in diameter. Example electrode materials include aluminum, aluminum alloys, copper, brass, or other conductive or semi-conductive materials.

The angular position of the pivotal connection may be controlled by an actuator **32**. The actuator **32** may be servo-hydraulic, pneumatic, electric motor driven, piezoelectric, etc., and may include screws, levers, and/or gears. Combinations of the shapes of hinged elements **26** and **28** with various positions of the actuator **32** allow for electrical contact to be maintained by the hemming apparatus **10**. One example is shown in, and discussed in further detail with reference to FIGS. **3A-3D**.

Referring back to FIG. **1**, the roller assembly **16** may contact the workpiece **20** to cause the portion of the workpiece **20** to bend when the pulsed electric current is flowing through the portion of the workpiece **20**. As such, pressure from the roller assembly **16** and pulsed electric current may be applied to the workpiece **20** simultaneously. The bending is caused by the roller assembly **16** contacting the workpiece **20** with application of sufficient force to plastically deform the workpiece **20**. A first portion of the hemming process may form a flange edge on the workpiece **20**. The flange edge may be formed by bending the portion of the workpiece **20** around a die form (e.g., as shown in FIGS. **3A** and **3B** designated by reference numeral **34**). A second portion of the hemming process may form a finished hem on the workpiece **20**. The finished hem may be formed by further bending of the flanged edge. As such, the hemming apparatus **10** (and **10'**, **10"**, and **10'''**, as discussed further below) may form a hem on the workpiece **20**.

An example of a final hem may include a metal sheet that started as a substantially flat piece (e.g., as depicted in FIG. **3A**), which has been bent, e.g., folded back upon itself as depicted in FIG. **3D**. For example, a single sheet of metal may be used to form a hem at an edge surface thereof, where opposing face surfaces of the finished hem configuration are adjacent one another without an intervening member therebetween. It is to be understood, however, that opposing face surfaces of the finished hem configuration may have an intervening member pinched therebetween or may include an intervening void space captured therebetween. For example, a panel assembly may include a sheet of metal hemmed with another sheet of metal between the opposing face surfaces of the hemmed sheet. Further, examples of a final hem may include a gap between opposing face surfaces of the workpiece **20**.

It is to be understood that the electrodes **12**, **14** may be positioned in front of or behind the roller assembly **16** relative to a hemming direction **24**. In other words, the electrodes **12**, **14** may be placed in a leading position or in a trailing position relative to the hemming direction **24**. Further, examples according to the present disclosure may include another (second) roller assembly (not shown) used to continue deforming the workpiece **20** after the (first) roller assembly **16** passes along the workpiece **20**. For example, the roller assembly **16** may contact the workpiece **20**, the electrodes **12**, **14** may follow behind the roller assembly **16**, and the second roller assembly may follow behind the electrodes **12**, **14**. Still further, other examples may include a second pair of electrodes (not shown) to be used in conjunction with the second roller assembly. For example, as a part of a single processing stage, a first pair of electrodes **12**, **14** may pass along workpiece **20** followed by the roller assembly **16** to deform the workpiece **20** into a partially processed condition, and the second pair of electrodes may pass along the workpiece **20** followed by a second roller assembly to deform the workpiece **20** into a further processed condition. As mentioned above, the second set of electrodes may also be used to anneal the deformed areas of the workpiece.

In the examples disclosed herein, it is desirable to control the temperature in the deformation zone of the workpiece **20** (i.e., the area of the workpiece **20** that is deformed) as the electric pulse is applied. The temperature in the deformation zone may be controlled by adjusting a distance between the roller assembly **16** and the electrode(s) **12**, **14** and/or by alternating the waveform of the electric pulse. The desirable temperature in the deformation zone depends upon the material(s) that is/are being used. For magnesium, the desirable temperature in the deformation zone ranges from about 200° C. to about 300° C. In general, if the deformation zone temperature is too high for a given material (which, in some instances, is below the melting temperature of the material), the process may result in a coarse grained microstructure which leads to the material having poor formability. Similarly, if the deformation zone temperature is too low, the material will also have limited formability.

In an example, the roller assembly **16** may be located within an electrically effective range from the first and second electrodes **12**, **14**. The electrically effective range may be from about 2 mm to about 30 mm. In an example, the electrically effective range is from about 5 mm to about 30 mm. The respective distances of the roller assembly **16** to the first electrode **12** and to the second electrodes **14** may vary depending on the material of the workpiece **20** and, as noted above, the temperature rise in the deformation zone of the workpiece **20** due to the electric pulsing. In an example, a desirable deformation zone temperature may be achieved (using the device depicted in FIG. **4**) when the distance between the roller **17** and the electrode **12** is about 2 mm during the flanging step(s) (i.e., obtaining a 90° bend), and from about 5 mm to about 20 mm during the hemming step(s) (i.e., obtaining a 180° bend). In some instances, these distances are close to the thicknesses of the workpiece **20** during the respective steps.

It is to be understood that the pulsed electric current in the examples disclosed herein may have a triangular waveform with a very fast rising portion. The waveform may be a sawtooth type with a negative ramp, i.e., with an almost vertical rise and a slower decay. The decay may be exponential within microseconds. It is to be understood that the waveform may have a period ranging from about 2 microseconds to about 10 microseconds. The frequency may range from about 100 Hz to about 1,000 Hz. The current density applied may be from about 100 A/mm^2 to about 1,000 A/mm^2 The current density is calculated assuming uniform current flow across the whole cross section of contact. It is to be understood that strong, consistent electrical contact may ensure smooth passage of current into the deforming metal of the workpiece **20** and may avoid arcing, which may therefore avoid damage to the finished surface appearance.

It is further to be understood that power is delivered to the electrical circuit **22** by electrical power supply **18** after the electrodes **12**, **14** are in contact with the workpiece **20**. In an example, a sensor may be used to determine whether electrical contact is made between the electrodes **12**, **14** and the workpiece **20**. In another example, low voltage electric pulses may be initially applied to detect and ensure smooth electrical contact of the electrodes **12**, **14** with the workpiece **20** prior to applying higher voltage electric pulsing for hemming. Electrical contact of the electrodes **12**, **14** with the workpiece **20** may also be achieved with a contact paste or conductive lubricant. However, the use of such pastes or lubricants may be undesirable because of post-process washing or grinding that may be needed to remove such materials.

During power delivery, it is desirable to avoid electric arcing. It is to be understood that an appropriate spring force between the electrode **12**, **14** and the workpiece **20** may help to avoid arcing. Surface cleaning and/or brushing of the workpiece **20** prior to hemming may also be performed to remove surface asperities from the workpiece **20**. This also may help to avoid arcing.

In the example shown in FIG. **1**, the pulsed electric current is applied to the workpiece **20** within the electrically effective range from the roller assembly **16**. The current will increase the formability of the portion of the workpiece **20** receiving the pulsed electric current. The roller assembly **16** is utilized to form the hem along the portion.

FIGS. **3A-3D** schematically depict examples of the first hinged element **26** (and the corresponding electrode **12**) and the second hinged element **28** (and the corresponding electrode **14**) maintaining contact with the workpiece **20** during steps of the hemming process. Contact is shown during the flanging steps, as depicted in FIGS. **3A** and **3B**, and during the hemming steps, as depicted in FIGS. **3C** and **3D**. The pulsed electric current is applied at least in the flanging step of FIG. **3B** and the hemming steps of FIGS. **3C** and **3D**.

FIG. **3A** illustrates an example of the electrodes **12**, **14** contacting the workpiece **20** when the workpiece **20** is substantially flat. It is to be understood that workpiece **20** may be fixed in a position to be bent around die form **34** and may be fixed, for example, by a blank holder (e.g., as with blank holder **21** shown in FIG. **4**), during flanging. FIG. **3B** illustrates an example of the electrodes **12**, **14** contacting the workpiece **20** when the workpiece **20** is partially bent around the die form **34**. It is to be understood that workpiece **20** is bent to form an angle of approximately 90 degrees at the stage of flanging shown in FIG. **3B**. As compared to FIG. **3A**, FIG. **3B** shows electrodes **12**, **14** as being articulated in conjunction with workpiece **20** in order to maintain contact during hemming

FIG. **3C** illustrates a portion of a hemming step with relative articulation of the actuator **32**. The relative articulation allows the first hinged element **26** to separate from the second hinged element **28** at the insulator **31**, thereby allowing the electrodes **12**, **14** to remain in contact, respectively, as the workpiece **20** is bent further in the hemming process. FIG. **3D** illustrates another hemming step in which the first electrode **12** of the first hinged element **26** and the second electrode **14** of the second hinged element **28** maintain contact with the workpiece **20**. It is to be understood that the shape of first hinged element **26** and second hinged element **28** may vary to accommodate various shapes and fixturing configurations of workpiece **20**. For example, hinged element **28** may have a clearance or may deform to accommodate workpiece **20** as shown in FIGS. **3C** and **3D**.

It is to be understood that with the examples of roller hemming as disclosed herein, the workpiece **20** may or may not be manipulated (e.g., repositioned) by, or within, a fixture (not shown) between and/or during stages of the roller hemming process. In an example, the workpiece **20** may be initially held by the fixture in a certain position while forming a flange on the workpiece **20**. The certain position may be retained with operation of a blank holder **21** (e.g., as shown in FIG. **4**) clamping the workpiece **20** between opposing clamping surfaces of the blank holder **21** or between one clamping surface of the blank holder **21** and another surface (e.g., a surface of a busbar die form **42**). The workpiece **20** may thereafter be repositioned relative to the blank holder **21**, for example, by turning over the workpiece **20** within the blank holder **21** or beneath the blank holder **21**. In an example, if a top clamping surface of the blank holder initially contacted a top surface of the workpiece **20** for clamping, upon repositioning the workpiece **20**, the top clamping surface may thereafter contact a bottom surface of the workpiece **20** for clamping. It is to be further understood that various clamping mechanisms and/or die forms may be used to control the workpiece **20**. For example, complex surface contours and edge shapes of the workpiece **20** may require custom tooling that may be used in accordance with the present disclosure.

In another example, a fixture (not shown) may hold the workpiece **20** with a fixed connection during the various stages of the hemming process. In one such example, the fixture may articulate relative to the roller assembly **16** in order to perform the flanging and hemming operations. For instance, the roller assembly **16** may remain stationary while the fixture articulates thereabout. Alternatively, the fixture may remain stationary while the roller assembly **16** articulates thereabout. Further, the fixture and the roller assembly **16** may each articulate, moving in a coordinated manner to process the workpiece **20** in the flanging and/or hemming operation. For example, the fixture may be in motion while the workpiece **20** is also in motion.

FIG. **4** depicts another example of a roller hemming apparatus **10'**. This example includes roller assembly **16** operatively disposed as an end effector on a robotic arm **19**. This example also includes a busbar **36** to serve as the first electrode **12**. It is to be understood that the busbar **36** includes an electrical conductor **38** positioned to be in electrical contact with workpiece **20**. As such, the busbar **36**, via the electrical conductor **38**, may provide for electrical contact with the workpiece **20** as the roller assembly **16** travels along the workpiece **20**. The busbar **36** may also be clamped to the workpiece **20**.

FIG. **4** also depicts the roller assembly **16** with the second electrode **14** electrically connected thereto. FIG. **4** further depicts an example electric current pathway as indicated by phantom line **40**. The electric current pathway **40** may generally follow a path from the second electrode **14** through a portion of the roller assembly **16** and out through a roller **17** to contact the workpiece **20** and ultimately the first electrode **12**. It is to be understood that the electric current pathway **40** is approximate and may vary depending on the configuration of workpiece **20** (including shape and material) and the positioning of roller assembly **16** relative to electrode **12**, **14**, etc.

In this example, the roller **17** is the portion of the roller assembly **16** which is intended to contact the workpiece **20** for hemming. The roller **17** may be formed of a material that is relatively soft yet has sufficient stiffness and strength at temperatures up to at least 400° C. The roller material may have appropriate surface hardness and rigidity to achieve predetermined dimensional requirements and surface quality of the workpiece **20** after deformation. Further, the roller **17** may be conductive because (as mentioned above) it may be part of the electric circuit **22** (and the electric current pathway **40**). As an example, tool steel may be an appropriate option for the roller **17** when roller hemming aluminum and/or magnesium sheets. An example tool steel roller may have a surface hardness ranging from about 50 HRC to about 55 HRC. It is to be understood that "HRC" means Rockwell C-scale hardness measurement units.

FIGS. **5**A and **5**B depict an example of the busbar **36** with electrical isolation components in an elevated stage and a depressed stage, respectively. Busbar **36** is shown with rubber insulation components (e.g., reference numerals **44**, **46**, **47**) positioned between the busbar **36** and a busbar die form **42**. It is to be understood that the rubber insulation components provide electrical isolation of the electrical components of the busbar **36** from the busbar die form **42**. Shown, for example, are a rubber cylinder **44** and rubber busbar side walls **46** and **47** placed within busbar die form **42** to electrically isolate the electrical conductor **38** of the busbar **36** from the busbar die form **42**. In the elevated stage, the insulation components **44**, **46**, **47** may push the electrical conductor **38** to extend beyond the surface of the busbar die form **42**.

FIG. **5**B shows the busbar **36** (and the electrical conductor **38**) in a depressed state, i.e., when the electrical conductor **38** is depressed by the workpiece **20** (which has been removed for clarity). In this state, better electrical contact is achieved between the workpiece **20** and the electrical conductor **38** due, at least in part, to a recovering force of the compressed rubber component **44**. This depressed state (with force applied on the workpiece **20** from the busbar **36**) may help to avoid arcing.

It is to be further understood that other insulating materials (e.g., polymers, composite insulating materials, or other insulating materials) may be used as the electrical isolation components in place of the rubber insulation components.

In both FIGS. **5**A and **5**B, the busbar **36** is shown in electrical connection with a clamping tab **48**, which connects a wire **50** to busbar **36**. Attachment of the wire **50** to clamping tab **48** is shown using fasteners, including a bolt **52** and a nut **53**. It is to be understood that other fastening means may be used also, e.g., welding, spring clips, etc.

FIGS. **6**A and **6**B depict an example of a portion of the roller assembly **16** as shown in FIG. **4**. These figures illustrate electrical isolation of certain components of the roller assembly **16** so that a current pathway may be isolated within the roller assembly **16** in a desirable manner. Insulation components are included for electrically isolating the current pathway (not shown) within the roller assembly **16**. In this example, the current pathway generally follows a path from a roller assembly clamping tab **56** to the roller **17** (not shown in FIGS. **6**A and **6**B) for contact with the workpiece **20**. Electrical isolation of the tab **56** and the roller **17** from the remainder of the roller assembly **16** may be provided by insulation layer **54**, insulating washers **58**, and insulating cylinders **60**, which are fastened to roller assembly **16** by allen head cap screws **62** with washers **64**. It is to be understood that insulation layer **54**, insulating washers **58**, and insulating cylinders may be made of various insulating materials as discussed above with reference to the insulating components of the busbar **36**. It is further to be understood that while cap screws **62** and washers **64** are shown in FIGS. **6**A and **6**B, other fastening means may be used, e.g., welding, spring clips, etc.

FIGS. **7**A and **7**B show an example of the hemming apparatus **10'** in operation, performing a flanging step and a hemming step, respectively. FIG. **7**A is substantially similar to FIG. **4**. At this step, the pulsed electric current is applied to the workpiece **20** as the roller **17** glides along the workpiece **20** to form a flange. The pulsed electric current enhances/improves the formability of the deformed portion of the workpiece **20** so that less force (e.g., compared to the force applied during traditional hemming) may be applied to the workpiece by the roller **17** in order to form the flange. Between the steps shown in FIGS. **7**A and **7**B, the workpiece **20** is repositioned with respect to the blank holder **21** so that the flange can be further folded. In FIG. **7**B, the pulsed electric current is continuously applied as the roller assembly **16** continues to process the workpiece **20** from the flanged condition into a hemmed condition.

FIGS. **8**A-**8**F depict still another example of a roller hemming apparatus **10"**. In this example, the first electrode **12** is part of the roller assembly **16** and the second electrode **14** is disposed on a wiper **66**. The first electrode **12** in this example is electrically connected to the roller **17** through the roller assembly clamping tab **56** as previously described in reference to FIGS. **6**A and **6**B. The wiper **66** is to provide for sliding electric contact on the workpiece **20**. The wiper **66** may be operable to translate relative to the workpiece **20** with the roller assembly **16**.

Referring primarily to FIG. **8**B, wiper **66** may be retained within a bracket assembly **74** and may be operable for axial translation along wiper primary axis **67** relative to bracket assembly **74**. Wiper **66** may operate with a spring **76** and an insulating collar **78** between the bracket assembly **74** and a wiper clamping tab **80**. The spring **76** operates to urge the wiper **66** into contact with the workpiece **20** by applying a force on the wiper **66** against the bracket assembly **74**. Wiper clamping tab **80** receives electrical connection for wiper **66** by means of a bolt **77** and nut **79** to clamp the wiper clamping tab **80** and a wire **81** (i.e., electrode **14**) together. Wiper clamping tab **80** may maintain electrical connection with wiper **66** by fastening means similar to that described for the electrical connection of busbar **36** of FIGS. **5**A and **5**B. The wiper **66** has sufficient electrical conductivity and may be made of copper, graphite, etc. An electric brush may be installed at one end of the wiper **66** to ensure sufficient electric contact, for example, during relative motion between the wiper **66** and the workpiece **20**. In an example, the surface contact patch of wiper **66** may be 5 mm×5 mm (25 mm^2)

FIGS. **8**A, **8**B, **8**C, and **8**F show details of fixturing for the wiper **66** including positioning of the wiper **66** relative to the roller assembly **16**. In an example, the wiper **66** and the roller assembly **16** are mounted for respective motion therebetween on a common frame mounting **68**. The common frame mounting **68** may include various supporting structures for holding the wiper **66** and roller assembly **16** in position to contact the workpiece **20**. In an example, common frame mounting **68** may include an arcuate telescoping connection **70** to control a respective position of the wiper **66** and the roller assembly **16**.

Referring primarily to FIGS. **8**A and **8**C, in an example, the arcuate telescoping connection **70** may include an inner tube section **71** and an outer tube section **73** to translate with respect to one another. The inner tube section **71** may be operable to travel within the outer tube section **73**, i.e., inner tube section **71** may telescope from within outer tube section **73**. Extending the inner tube section **71** out from within the outer tube section **73**, i.e., exposing more of the inner tube section **71**, creates a greater angle between the wiper primary axis **67** (shown in FIG. **8**B) and a roller assembly axis **23** (shown in FIG. **8**A). The roller assembly axis **23** is defined as a line passing approximately through the point of contact of the roller **17** (with the workpiece **20**) and extending substantially perpendicular to the hemming direction **24** and substantially perpendicular to a roller primary axis **25** (shown in FIG. **8**A). A set screw **72** may be operable to fix the angular position of the wiper **66** relative to the roller assembly **16**. The set screw **72** may also be used as a stop in order to prevent the inner tube section **71** from protruding beyond the outer tube section **73**. In this way, the inner tube section **71** remains inside the outer tube section **73**. It is to be understood that various fastening means may be used to fix the angular position of the wiper **66** relative to the roller assembly **16**, e.g., spring clips, cotter pins, etc.

FIGS. **8**D and **8**E depict two stages of an example roller hemming process and two configurations of wiper contact and electrical pathways. In an example, wiper **66** may contact the workpiece **20** as shown in a flanging step as depicted in FIG. **8**D. In another example, wiper **66** may contact die form **34** as shown in a hemming step as depicted in FIG. **8**E. It is to be understood that various configurations of wiper contact may be required for flanging and hemming steps with various workpiece shapes and configurations of fixturing the workpiece **20** for processing. For example, the wiper **66** may contact a top surface of workpiece **20** in one step, and the wiper **66** may contact the die form **34** in another step. When the wiper **66** contacts the die form **34**, it is to be understood that the die form is conductive in order to apply the pulsed electric current to the workpiece **20** sitting on the die form **34**.

As shown in the cutaway view of FIG. **8**F, inside the arcuate telescoping connection **70**, a coil spring **75** may be positioned within inner tube section **71** and outer tube section **73**. Coil spring **75** may operate to assist in manipulating the angular position of the wiper **66** relative to the roller assembly **16**. For example, coil spring **75** may provide resistance between inner and outer tube sections **71**, **73**.

FIGS. **9**A-**9**C depict still another example of the roller hemming apparatus **10'''** with the roller assembly **16** and the wiper **66** having a geared connection **82**, **84** to control a respective position of the wiper **66** and the roller assembly **16**. An angular position of the wiper **66** relative to roller **17** may be controlled by a driving gear **82** having teeth that meshingly engage driven gear teeth, for example, as shown on a toothed arcuate section **84** in FIGS. **9**A-**9**C. Toothed arcuate section **84** may be operably connected to wiper **66** by a bracket assembly **86**. Details of operation of wiper **66** including spring **76**, electrical connection of electrode **14**, and contact with workpiece **20** are similar to that discussed above with reference to FIGS. **8**A-**8**F. It is to be understood that various other mechanisms may be used to assist in positioning the toothed arcuate section **84**, e.g., actuators that are servo-hydraulic, pneumatic, electric motor driven, piezoelectric, etc. and may include screws, levers, and/or gears, etc.

To further illustrate the present disclosure, examples are given herein. It is to be understood that these examples are provided for illustrative purposes and are not to be construed as limiting the scope of the present disclosure.

EXAMPLES

Comparative Example 1

FIGS. **10**A and **10**B depict a top, perspective view and a bottom surface view of a magnesium sheet that was exposed to a hemming process without the pulsed electric current of the present disclosure. In this comparative example, the magnesium sheet was used as the workpiece and hemming was attempted using a traditional process. The magnesium sheet was exposed to flanging, but the sheet cracked after slight bending was performed. FIG. **10**A illustrates the top and one side of the workpiece. As shown on the bottom portion of the side, a cracking line **88** formed in the workpiece as a result of the hemming process. FIG. **10**B is a view of the bottom surface of the workpiece showing the cracking line **88** extending along the bottom surface of the workpiece.

Example 2

FIGS. **11**A and **11**B depict different views of another magnesium sheet that was bent using the electric pulse assisted roller hemming process according to the present disclosure. In this example, the magnesium sheet was used as the workpiece, and was hemmed with a second magnesium sheet (as shown in FIG. **11**B). Using a device similar to that shown in FIG. **4**, the magnesium sheet was exposed to six different passes of the roller **17**, which functioned as one of the electrodes. The other electrode was a busbar (similar to busbar **36**). During the flanging stage, three roller passes were performed to continuously bend the magnesium sheet to achieve a 90° bend. The workpiece was then flipped over 180°, and the second magnesium sheet was placed onto the workpiece so that an edge of the second magnesium sheet abutted the 90° bend. During the hemming stage, three roller passes were performed to continuously form the hem edge **90** shown in FIG. **11**B. The electric pulse was applied to the magnesium sheet throughout both the flanging stage and the hemming stage. For each pass, the travel velocity of the roller was 20 mm per minute. FIG. **11**A depicts a view facing the curved surface of the hemmed edge **90**. FIG. **11**B depicts a perspective side view including hemmed edge **90**. Unlike Comparative Example 1, no cracks formed in the magnesium workpiece after electric pulse assisted bending was performed.

It is to be understood use of the words "a" and "an" and other singular referents may include plural as well, both in the specification and claims, unless the context clearly indicates otherwise.

It is to be understood that the terms "connect/connected/connection" and/or the like are broadly defined herein to encompass a variety of divergent connected arrangements and assembly techniques. These arrangements and techniques include, but are not limited to (1) the direct communication between one component and another component with no intervening components therebetween; and (2) the

communication of one component and another component with one or more components therebetween, provided that the one component being "connected to" the other component is somehow in operative communication with the other component (notwithstanding the presence of one or more additional components therebetween).

It is to be understood that the ranges provided herein include the stated range and any value or sub-range within the stated range. For example, a range from about 100 Hz to about 1,000 Hz should be interpreted to include not only the explicitly recited limits of about 100 Hz to about 1,000 Hz, but also to include individual values, such as 120 Hz, 500 Hz, 800 Hz, etc., and sub-ranges, such as from about 100 Hz to about 210 Hz, from about 800 Hz to about 950 Hz, etc. Furthermore, when "about" is utilized to describe a value, this is meant to encompass minor variations (up to +/−10%) from the stated value.

While several examples have been described in detail, it will be apparent to those skilled in the art that the disclosed examples may be modified. Therefore, the foregoing description is to be considered non-limiting.

The invention claimed is:

1. A sheet metal roller hemming apparatus, comprising:

a first electrode to electrically connect to an electrical power supply and a sheet metal workpiece, wherein the first electrode is a busbar including an electrical conductor positioned to be in electrical contact with the workpiece;

a second electrode to electrically connect to the electrical power supply and the sheet metal workpiece to cause pulsed electric current having a pulse frequency from about 100 Hz to about 1000 Hz to flow through a portion of the workpiece to locally increase formability in the portion of the workpiece via an electroplasticity effect and to form a hem, wherein the second electrode is a roller assembly; and

rubber insulation components positioned between the busbar and a die form that supports the busbar, wherein the rubber insulation components include a rubber cylinder and two rubber busbar side walls placed within the die form to electrically isolate the busbar from the die form and wherein the rubber cylinder urges the busbar into contact with the sheet metal workpiece.

2. The sheet metal roller hemming apparatus as defined in claim **1** wherein the busbar is clamped to the workpiece.

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